Biennial patterns in Alaskan sockeye salmon ocean growth are associated with pink salmon abundance in the Gulf of Alaska and the Bering Sea

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Abstract

In response to ocean heating and hatchery production, pink salmon (*Oncorhynchus gorbuscha*) returning from the North Pacific Ocean steadily increased after 1975, leading to concerns about their influence on food webs and competition with other species. Using measurements of distance between scale annuli of 24 584 individual sockeye salmon (*O. nerka*), we examined growth during their 2 or 3 years at sea from 1977 to 2015 for eight populations in Alaska. We found significant, negative autocorrelations at 1 lag year in annual growth of sockeye salmon, with a consistent pattern of lower growth in odd years, i.e. opposite to the biennial pattern of pink salmon abundance. Peak pink salmon abundances reduced growth of sockeye salmon from 7 to 14% during the second year in the ocean compared with growth when pink salmon abundance was low, while third-year growth was reduced up to 17%. The overall effect of pink salmon abundance on sockeye growth was over two times greater than the effect of sockeye salmon abundance. Pro- duction hatcheries and ocean heating contribute to the competitive dominance of pink salmon, underscoring the need to consider this unintended anthropogenic effect on the growth and productivity of sockeye salmon throughout the North Pacific.

Conclusion

The reduction in annual growth of the eight sockeye salmon populations in relation to increasing pink and sockeye salmon abundances adds to the growing body of evidence indicating a limited capacity of the ocean to support both wild and hatchery salmon (Peterman 1978, 1984a, 1984b, Cooney and Brodeur 1998, Pearcy et al. 1999, Holt et al. 2008, McMillan et al. 2023, Ruggerone et al. 2023). During 2005–2015, ∼82 million hatchery pink salmon returned per year from the North Pacific Ocean (Ruggerone and Irvine 2018), a value that is more than all wild chum salmon and about equal to wild sockeye salmon during this period. Hatcheries, primarily in Alaska and Russia, continue to release ∼1.4 billion pink salmon per year, 2000–2022 (NPAFC 2023), even though total pink salmon abundance has reached record-high levels in recent years (e.g. ∼800 million fish in 2021; Ruggerone et al. 2023). The growing abundance of wild and hatchery pink salmon in the North Pacific since 1955 is highly correlated with the North Pacific ocean heat content (*r* = 0.71, a measure of the total energy absorbed and stored by oceans; Levitus et al. 2012, NOAA 2022), suggesting that humans have contributed to the rapid increase in pink salmon abundance through both hatchery production and their contributions to ocean heating (Ruggerone et al. 2023). The mean annual return of ~82 million hatchery pink salmon during 2005–2015 was estimated to reduce sockeye salmon productivity by ~5% in the Bering Sea, 6% in the Gulf of Alaska, and 15% in British Columbia and southeast Alaska after accounting for sea surface temperature (Connors et al. 2020). Hatchery pink salmon contribute to the release of 5.1 billion hatchery salmon per year (NPAFC 2023), and total hatchery salmon production is estimated to represent 40% of the total immature and adult salmon biomass in the North Pacific Ocean, largely from pink and chum salmon (Ruggerone and Irvine 2018). Thus, hatchery production, coupled with human-derived climate change (Litzow et al. 2023) likely has had unintended effects on wild salmon.

In conclusion, we present new evidence indicating the effect of pink and sockeye salmon abundance on annual growth of sockeye salmon originating from seven watersheds in the Gulf of Alaska region, and one in the southeastern Bering Sea. Our findings build upon robust and consistent findings showing the competitive dominance of pink salmon over sockeye salmon. It is important to recognize that in the present era, hatchery releases represent a classic 'zero-sum' game, where an incremental increase in hatchery releases results in some loss of growth and productivity of wild salmon through increased competition at sea. Understanding this dynamic is critical for making responsible decisions related to the management of salmon hatcheries and conservation of wild Pacific salmon.

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North Pacific pink salmon are true competitors
A new study published today in ICES Journal of Marine Science involved careful examination of nearly 25,000 scales collected from Alaskan sockeye salmon and reveals a clear pattern of reduced growth in odd years in the North Pacific since 1977, and the culprit appears to be pink salmon, who consume many of the same prey as sockeye.

The study relies on a "natural experiment" that occurs at the scale of the North Pacific – odd years tend to have much higher abundance of pink salmon owing to their two year fixed life cycle. "When you plot their abundance over time, you see this very regular, sawtooth pattern" describes Pete Rand, the study's lead author and an ecologist at the Prince William Sound Science Center. Odd year lineages of pink salmon (the generations that started as fertilized eggs in river gravel in odd years) have been roughly twice as abundant as even year lineages, and this pattern has persisted in the North Pacific for decades.

Past studies have shown how pink salmon compete with sockeye salmon for prey at sea and affect their growth, but this study reveals the effect extends to many populations that originate in Alaska. The study's authors reveal that eight populations of sockeye salmon in Alaska grew less (on average up to 17% less) in odd ocean years when competition at sea is more intense. For sockeye that enter the ocean in an odd year and return two years later, this translates into smaller body size when they return to spawn (a reduction of 2% in their length or a 6% drop in mass). The authors also noted that there has been a long term decline in sockeye salmon growth with increasing abundance of pink salmon. This has important implications for sockeye fisheries and the fish's own reproductive fitness.

"To understand this phenomenon, we had to look through both the microscope and the macroscope", says Rand. The study linked the changes in growth measured in millimeters on thousands of fish scales to the abundance of pink salmon that occupy around 15 million square kilometers or nearly 6 million square miles of ocean. The effect is driven by population cycles of pink salmon originating from North America and as far away as the Kamchatka peninsula in Russia. The cycles are a trait of wild pink salmon populations, but pink salmon released from production hatcheries contributes to the overall effect. The authors liken it to a "zero-sum game", where any additional production of hatchery pink salmon in the future can contribute to declines in growth of sockeye salmon across a broad swath of coastal Alaska.

Both species are important to a variety of fisheries in Alaska (including commercial, sport, and subsistence fisheries), and the authors encourage fishery and hatchery managers to consider this trade-off when making decisions that affect overall salmon abundance in the ocean.

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